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Construction of the Superconducting ECR Ion Source Venus

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Abstract

A new, very high magnetic field superconducting ECR ion source, *VENUS*, is under development at the LBNL 88-Inch Cyclotron. It will boost the maximum energies and intensities for heavy ions from the cyclotron particularly for ions with mass greater than 60. It will also serve as R&D ion source for the proposed Rare Isotope Accelerator (RIA) project in the US, which requires up to 10 pμA of U^{30+}. The superconducting magnet structure consists of three solenoids and six racetrack coils with iron poles forming the sextupole. The coils are designed to generate a 4 T axial mirror field at injection and 3 T at extraction and a radial sextupole field of 2.4 T at the plasma chamber wall. Test results of the magnet coils, which exceeded design requirements with minimum training, are presented. The magnet assembly with its cryostat will be enclosed by an iron shield and therefore must be designed to withstand any possible forces between coils and iron, which can be as high as $3.4 \cdot 10^5$ N (35,000 kgf). The low energy beam transport line (LEBT) and mass analyzing system of the ion source is designed to transport a proton-equivalent current of 25 mA at 20 kV extraction voltage. The design of the ion source and LEBT will be discussed.

1. Introduction

The superconducting Electron Cyclotron Resonance Ion Source (ECRIS) *VENUS*, whose R&D progress has been previously documented [1,2], is presently under construction. The *VENUS* project aims for following significant improvements for ECRIS:

(1) Reach the highest magnetic fields so far obtained in an ECRIS to improve plasma confinement.
(2) Utilize a commercially available 10 kW-CW 28 GHz gyrotron amplifier to take advantage of the high magnetic fields and the large plasma volume.
(3) Develop new clamping schemes for the superconducting coils in order to withstand the strong magnetic forces.
(4) Use state of the art cryogenic equipment, utilizing cryocoolers and High Temperature Superconductor (HTS) leads, to eliminate the need of a liquid-He filling system.
(5) Develop a cold mass suspension system, which can withstand the strong magnetic forces that occur in ECRIS designs and simultaneously maintain a low heat leak to allow the use of cryocoolers.
(6) Develop a miniature high-temperature oven (~2000° C) to be axially inserted into the ion source.
(7) Develop a thin walled aluminum plasma chamber, which allows sufficient cooling of the walls and maintains a maximum plasma volume.
(8) Increase the electrical insulation capability of the source in order to facilitate operation up to 60 kV extraction voltages.
(9) Develop a beam extraction and analyzing system, which can transport the intense heavy ion beams. The high magnetic field (up to 3 T) of the extraction region results in different focusing properties for different ions thus requiring a versatile transport system.

In order to demonstrate these technology advancements some VENUS design parameters are compared with the respective parameters of the two existing LBL ECR ion sources [3] in Table I.

2. Source design

Figure 1 shows the mechanical layout of the VENUS ion source. The plasma chamber is made out of an aluminum tube with gun-drilled water cooling-channels. Aluminum provides a source of cold electrons for the plasma. The technique has been developed and tested on the LBNL AECR [4]. In addition to the favorable secondary emission properties of the aluminum wall, which come from the formation of Al_2O_3 on the surface, the aluminum is very resistant to plasma etching. This reduces contamination of the plasma by ions from the wall. To further increase the vacuum cleanliness, the whole source and beamline are metal sealed.

Three off-axis microwave feeds as well as two ovens and a biased disk are inserted from the injection spool. We have developed a high temperature (>2000°C) miniature oven, which is similar in concept to the high temperature oven developed at LBL and in use since 1987 [5]. The new oven is miniaturized and fits on a $2\frac{3}{4}''$ conflat flange. It is currently fabricated and will be first tested in the AECR source. The biased disk is star-shaped to terminate the plasma and still provide enough space for the waveguide, oven penetrations and pumping. The open space around the biased disk is the only vacuum-pumping opportunity for the plasma chamber. Taking into account the limited conductance of

Table I. *Comparison between LBNL ECR Ion Sources.*

	ECR	AECR	VENUS
Magnetic Field: (Ampere-Turns)	231,000	317,000	3,000,000
Magnetic Field: (Peak Field)	0.4 T	1.7 T	4 T
Microwave: (Frequency)	6.4 GHz	10 GHz + 14 GHz	18 GHz + 28 GHz
Microwave: (Total Power)	600 W	2,600 W	14,000 W
Extraction: (High Voltage)	10 kV	15 kV	30 kV

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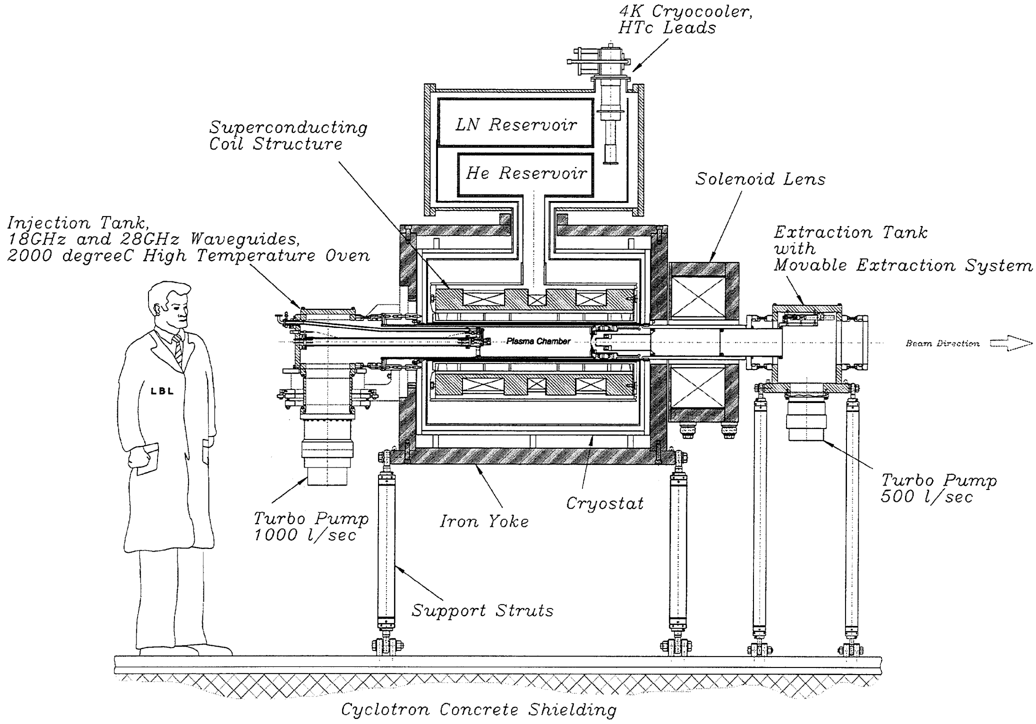

Fig. 1. Section view of the VENUS ion source.

the injection tank a 1000 l/s turbo pump will allow sufficient pumping of the plasma chamber.

The *VENUS* cryostat is being constructed at WANG NMR Inc. in Livermore, CA, where all of the superconducting magnet coils were wound. The fabrication of the magnet structure was completed fall 1999. Its design was improved in several respects compared to a prototype magnet [2,6]. The sextupole coils reached more than 125% of the coil design current after only five training quenches when tested by itself. At maximum solenoid field, the sextupole coils reached more than 125% of the design field after four additional training quenches. (The solenoid coils experienced no quenches up to the power supply limits in a previous test.) The *VENUS* magnet system will provide the highest magnetic fields yet achieved in an ECR coil configuration. These field levels are more than sufficient for optimal operation at a microwave frequency of 28 GHz. Fabrication of the cryostat and source components will continue until end of this year. First beam tests are scheduled for summer 2000 after assembly of the beamline.

3. Low energy beam transport

The effect of the high magnetic ion-source field (up to 3 T) on the ion beam extraction and matching to the beam line has been investigated in [2,7]. The various charge states focus differently in the high magnetic field of a superconducting ECR ion source (see Fig. 2). This leads to typical emittance patterns, where each charge state is oriented differently in phase space. For the 88-Inch Cyclotron operation, the LEBT must be versatile enough to transport many different ion beams and charge states at varying extraction voltages.

The tuning flexibility of the existing LBL ECR beamlines comes from the insertion of a solenoid lens between the extraction and the analyzing magnet. In this scheme the solenoid lens focuses the extracted beam to the first focal point of the analyzing magnet. Ion optics simulations show that a small waist in front of the analyzing magnet induces strong aberrations in high-space-charge ion beams. Further, the magnetic field of the solenoid lens must be more than one Tesla for the extraction voltages (up to 30 kV) considered for VENUS.

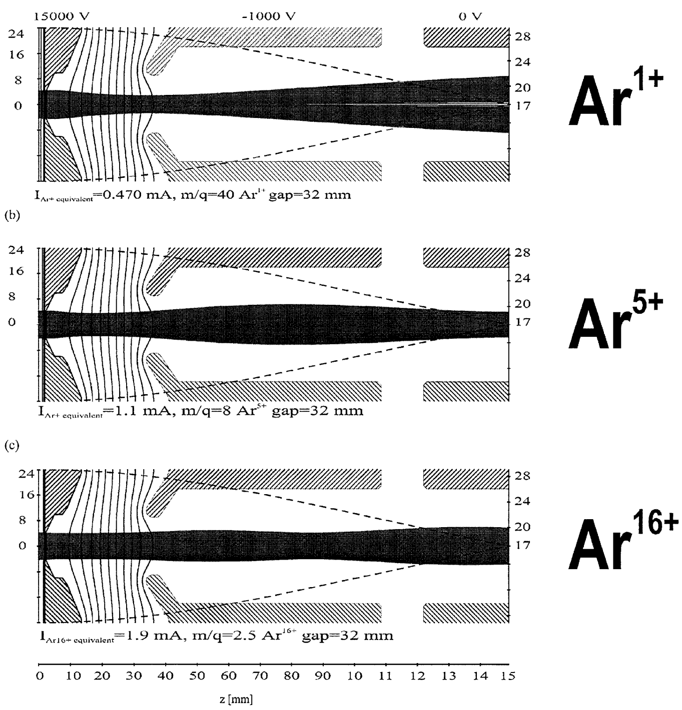

Fig. 2. Different charge states focus differently in the high magnetic field of a superconducting ECR ion source. The dotted line represents the axial magnetic field strength (the right-hand scale goes from 1.7 up to 3 Tesla). The extracted charge state distribution is normalized to the indicated single charge states (as described in [7]). The total extracted beam current is the same for all three simulations. The extraction hole diameter is 8 mm.

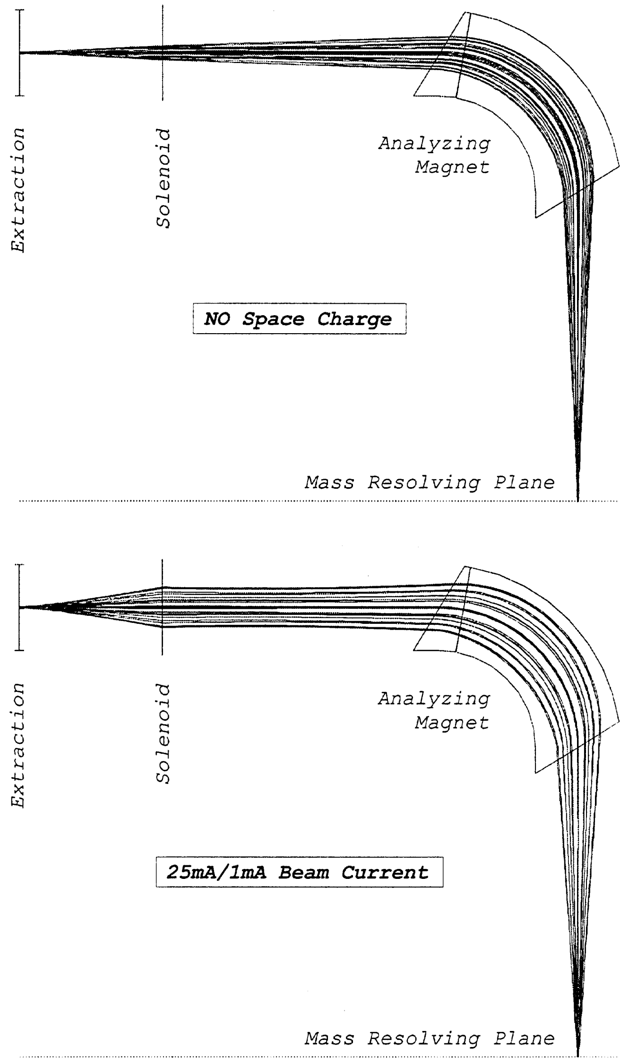

Fig. 3. VENUS low energy beam transport simulation (GIOS, [8]) with and without space charge (The second number refers to the current after the analyzing magnet).

Therefore, we have decided to eliminate the waist in front of the analyzing magnet. Now the sole purpose of the solenoid lens is to adjust the angle of the beam going into the magnet (see Figs 3 and 4). Since the actual beam diameter cannot be controlled with a single solenoid lens a sufficiently large magnet gap must be chosen to accommodate the highest anticipated beam intensities. To meet these requirements a multipurpose analyzing magnet is currently in design and will incorporate two quadrupole and two

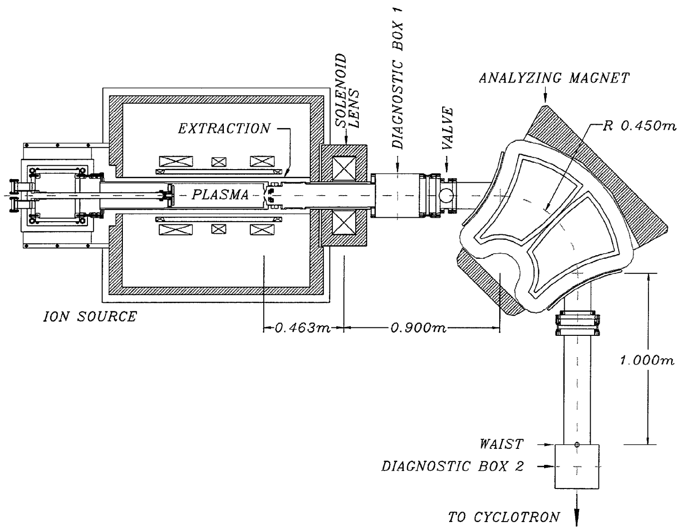

Fig. 4. VENUS beamline layout.

sextupole moments at the magnet edges and two more sextupole moments in the magnet center to compensate for higher order effects. 3D magnet calculations (Tosca 3D) are necessary to define the correct pole shape of the analyzing magnet. The resolution of the magnet will be $m/\Delta m \sim 100$, its beam radius 45 cm and its pole gap 22 cm.

Acknowledgements

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